IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

EXPRESS MAIL NO.:EL 627510445 US
APPLICANT(S):Junya SHIMIZU
FILING DATE: Herewith ART UNIT:
TITLE:SIGNAL SEPARATION METHOD, SIGNAL PROCESSING APPARATUS, IMAGE PROCESSING APPARATUS, MEDICAL IMAGE PROCESSING APPARATUS AND STORAGE MEDIUM FOR RESTORING MULTIDIMENSIONAL SIGNALS FROM OBSERVED DATA IN WHICH MULTIPLE SIGNALS ARE MIXED
ATTORNEY DOCKET NO.JP920000339JP1 / 954-010483-US(PAR)

Commissioner of Patents
Washington, D.C. 20231

PRELIMINARY AMENDMENT

Dear Sir:
Please amend the above-identified, enclosed patent application as follows:

IN THE SPECIFICATION

Please delete the paragraph starting on page 1, line 19 through page 2, line 8, and replace with the following replacement paragraph:

As seen in an example of the observation of multiple frames in which text have been overwritten on a background image for such as moving pictures, there are situations where multiple multidimensional signals that are originally independent are mutually mixed and observed in plural conditions. A technique for

determining signals prior to mixture only from observed signals, in which multiple multidimensional signals have been mixed mutually, is expected to be used in various fields in the future. These fields include, for example, separation between character information and image information when acquiring images from a scanner or the like, restoration of medical images for extracting necessary information, enhancement and restoration of blurred images, noise reduction by image reconstruction using feature extracting components of observed images contaminated by noise, classification and recognition of face data and multidimensional data using feature extracting components of observed multidimensional signals such as an image, etc.

Please delete the paragraph starting on page 2, line 25 through page 3, line 13, and replace with the following replacement paragraph:

Fig. 1 shows two signal sources s_1 and s_2 by way of example. For this, n linear weighted sums $x_1(t)$, ..., $x_n(t)$ are to be observed, which is expressed as follows and observed by an observation apparatus.

[Equation 1]

$$\underline{x}(t)=\underline{A}\underline{s}(t)$$

where each element is represented as follows.

[Equation 2]

$$\underline{x}(t)=[x_1(t)x_2(t)\cdots x_n(t)]^T$$

$$\underline{s}(t)=[s_1(t)s_2(t)\cdots s_m(t)]^T$$

where it is assumed to be $n \geqq m$. Furthermore, assuming that $n \times m$ mixing matrix is $\underline{A}$, which is to be a full rank matrix, i.e., a matrix where an inverse matrix of $m \times m$ matrix $\underline{A}^H \underline{A}$ exists. Hereinafter, a lowercase letter

with an underline represents a vector, an uppercase letter with an underline represents a matrix, a superscript T represents transposition, and a superscript H represents Hermitian conjugate (i.e., conjugate transposition).

Please delete the paragraph starting on page 4, line 19 through page 5, line 23, and replace with the following replacement paragraph:

However, as the probability distribution of original signals is practically unknown, the mutual information can not be made directly to be an object of minimization operation. Therefore, the signal separation is often performed by optimizing a valuation amount that is equal or approximately equal to the mutual information. For example, literature 1 "International Journal of Neural Systems", vol. 8, Nos. 5 & 6, pp. 661-678, October/December 1997, describes that a mutual information is able to be minimized if finding a transformation matrix $\underline{W}$ that optimizes the sum of the fourth-order cumulants with a zero time delay for each original signal (i.e., maximizing if the kurtosis is positive or minimizing if the kurtosis is negative), on the condition that the observed signals have a kurtosis with the same sign, a covariance matrix is bounded, whitening has been performed, and a separation matrix $\underline{W}$ is a unitary matrix (i.e., $\underline{W}^H \underline{W} = \underline{I}$ (unit matrix)). Note that the kurtosis refers to a numeric obtained by the following calculation for an observed signal u_i.

[Equation 5]

$$E\{u_i^4\} - 3[E\{u_i^2\}]^2$$

where $E[\cdot]$ represents an expectation operation. The

whitening means making signal vectors uncorrelated each other to make the variance 1, the fourth-order cumulant is a statistic represented by the following equation.

[Equation 6]

$$
\begin{aligned}
c_4(k_1, k_2, k_3) = {} & E\{u_i(t)u_i(t+k_1)u_i(t+k_2)u_i(t+k_3)\} \\
& - E\{u_i(t)u_i(t+k_1)\}E\{u_i(t+k_2)u_i(t+k_3)\} \\
& - E\{u_i(t)u_i(t+k_2)\}E\{u_i(t+k_1)u_i(t+k_3)\} \\
& - E\{u_i(t)u_i(t+k_3)\}E\{u_i(t+k_1)u_i(t+k_2)\}
\end{aligned}
$$

The zero time delay means that k_1, k_2 and k_3 are zero in the above equation.

Please delete the paragraph starting on page 15, line 5 through page 16, line 2, and replace with the following replacement paragraph:

A signal separation method according to the invention is applied to the field of extracting an accurate change of brain activity when restoring a medical image to extract necessary information from medical images such as fMRI (functional magnetic resonance imaging). It is also applied to extraction of an original image prior to blurring by enhancing and restoring a blurred image, or noise reduction by means of image reconstruction using feature extracting components of an observed image that is contaminated by noise. Furthermore, it is conceivable that the present invention will be applied to classification and recognition of face data or multidimensional data by means of feature extracting components of observed multidimensional signals of images or the like, including face recognition in biometrics or geographic analysis from satellites. That is, a signal separation method according to the present invention is widely applicable to a problem that needs to separate

original signals only from signals where a general multidimensional signal train is observed in mixed state, irrespective of the state of the digital observed signals or analog observed signals, complex signals or real signals, etc., wherein the application of its derivative forms may be widely derived, so being not limited to the above examples. Note that a signal separation technique according to the present invention can be useful with a dedicated apparatus or a terminal, as well as a computer system having a variety of memories, controllers, and a display, etc.

Please delete the paragraph starting on page 17, line 14 through line 24, and replace with the following replacement paragraph:

In addition, though various proposals have been provided as to what kind of nonlinear function should be used, it is common to use threshold processing for changing a function to be used depending on whether the kurtosis of the observed signals is positive or negative, thereby selecting a function that enables an appropriate approximation of high order cumulants. Other various types of forms are also conceivable. Functions to be used include $\tanh(u)$, u^3, or $u-\tanh(u)$, etc. For example, $u-\tanh(u)$ is used when the kurtosis is positive, while tanh(u) is used when the kurtosis is negative.

Please delete the paragraph starting on page 19, line 17 through page 20, line 5, and replace with the following replacement paragraph:

In the calculation of $\underline{h}(t)$ 25, $\underline{h}(t)$ is calculated from

$\underline{P}(t-1)$ at the previous time and $\underline{y}(t)$. In the calculation of $\underline{g}(t)$ and ξ 26, each value is calculated using a forgetting factor β. This forgetting factor β is a constant of $0<\beta\leqq 1$, which may be usually 1, however, when a matrix $\underline{W}$ to be estimated varies with time, this forgetting factor β is set to smaller than 1 such as 0.99 or 0.98 to enable tracking for this varying. In the calculation of $\underline{P}(t)$ 27, $\underline{P}(t)$ is calculated, which is an inverse matrix of a covariance matrix of $\underline{y}(t)$, from $\underline{h}(t)$ calculated in the calculation of $\underline{h}(t)$ 25, input α, the forgetting factor β, and $\underline{g}(t)$ and ξ calculated in the calculation of $\underline{g}(t)$ and ξ 26. Note that initial values $\underline{P}(0)$ and $\underline{W}(0)$ are arbitrarily selected for these algorithms.

Please delete the paragraph starting on page 21, line 12 through line 23, and replace with the following replacement paragraph:

The algorithm shown in Fig. 4 is represented as follows.
[Equation 13]

$$y_i(t)=f(\underline{w_i}^H(t-1)\underline{x_i}(t))$$

$$\alpha=1-\gamma^{-2}$$

$$\underline{e_i}(t)=\underline{x_i}(t)-\underline{w_i}(t-1)y_i(t)$$

$$\xi=\frac{\beta d_i(t-1)+y_i(t)^* y_i(t)}{\beta d_i(t-1)+\alpha y_i(t)^* y_i(t)}$$

$$\frac{1}{d_i(t)}=\frac{1}{\beta}\left\{\frac{1}{d_i(t-1)}-\alpha\xi\frac{y_i(t)^* y_i(t)}{d_i(t-1)\{\beta d_i(t-1)+y_i(t)^* y_i(t)\}}\right\}$$

$$\underline{w_i}(t)=\underline{w_i}(t-1)+\underline{e_i}(t)[y_i(t)^*/\{\beta d_i(t-1)+y_i(t)y_i(t)^*\}]$$

$$\underline{x_{i+1}}(t)=\underline{x_i}(t)-\underline{w_i}(t)\underline{y_i}(t)$$

where $d_i(0)$ is any initial value, a superscript $*$ represents conjugate. $f(\cdot)$ represents a nonlinear

function such as tanh(·).

Please delete the paragraph starting on page 21, line 24 through page 22, line 9, and replace with the following replacement paragraph:

In Fig. 4, a flow of main algorithm is represented by a nonlinear function 41, calculation of an error signal $\underline{e_i}(t)$ 42, update of $\underline{w_i}(t)$ 43, and update of $\underline{x_{i+1}}(t)$ 45, wherein various amounts necessary for this main algorithm are calculated by each unit including calculation of ξ 46 and calculation of $\underline{d_i}(t)$ 47. z^{-1} is a delay for timing adjustment. The accuracy is enhanced by performing a unitarization operation when each $\underline{w_i}(t)$ is found or when all $\underline{w_i}(t)$ are found. For example, in the case of a real vector, Gram-Schmidt orthogonalization process may be applied, however, there is no need to restrict a method.

Please delete the paragraph starting on page 32, line 13 through line 24, and replace with the following replacement paragraph:

3) Noise reduction by the image reconstruction using feature extracting components of the observed images contaminated by noise

After classifying the observed images contaminated by noise into some independent components by the independent component analysis, noise reduction is performed by removing the components that are regarded as noise and synthesizing using an inverse matrix of the separation

matrix. As the method of the present invention has tolerance to noise, more accurate independent components than the prior art can be extracted, thereby allowing more efficient noise reduction.

Please delete the paragraph starting on page 35, line 5 through line 21, and replace with the following replacement paragraph:

[Description of the Symbols]
21: Nonlinear function
22: Calculation of error signal $\underline{e}(t)$
23: Update of $\underline{W}(t)$
24: Unitarization operation
25: Calculation of $\underline{h}(t)$
26: Calculation of $\underline{g}(t)$ and ξ
27: Calculation of $\underline{P}(t)$
31: Estimation filtering of $\underline{w_1}(t)$
32: Estimation filtering of $\underline{w_2}(t)$
33: Estimation filtering of $\underline{w_m}(t)$
41: Nonlinear function
42: Calculation of error signal $\underline{e_i}(t)$
43: Update of $\underline{w_i}(t)$
45: Update of $\underline{x_{i+1}}(t)$
46: Calculation of ξ
47: Calculation of $\underline{d_i}(t)$

REMARKS

In accordance with 37 C.F.R. §1.121 (as amended on 11/7/2000) the specification replacement paragraphs above are shown on separate pages marked up to show all the changes relative to the previous version of that section.

Respectfully submitted,

29Oct01

Date

Clarence A. Green, Reg. No.: 24,622
Perman & Green, LLP
425 Post Road
Fairfield, CT 06430
(203) 259-1800
Customer No.: 2512

Application No.: 954-010483-US(PAR)

Marked Up Specification Replacement Paragraphs

Page 1, line 19, through page 2, line 8.

As seen in an example of the observation of multiple frames in which text have been overwritten on a background image for such as moving pictures, there are situations where multiple multidimensional signals that are originally independent are mutually mixed and observed in plural conditions. A technique for determining signals prior to mixture only from observed signals, in which multiple multidimensional signals have been mixed mutually, is expected to be used in various fields in the future. These fields include, for example, separation between character information and image information when acquiring images from a scanner or the like, restoration of medical images for extracting necessary information, enhancement and restoration of blurred images, noise reduction by image reconstruction using feature extracting components of observed images ~~interfered~~contaminated by noise, classification and recognition of face data and multidimensional data using feature extracting components of observed multidimensional signals such as an image, etc.

Page 2, line 25 through page 3, line 13.

Fig. 1 shows two signal sources s_1 and s_2 by way of example. For this, n linear weighted sums $x_1(t)$, ...,

$x_n(t)$ are to be observed, which is expressed as follows and observed by an observation apparatus.

[Equation 1]

$$\underline{x}(t)=\underline{A}\underline{s}(t)$$

where each element is represented as follows.

[Equation 2]

$$\underline{x}(t)=[x_1(t)x_2(t)\cdots x_n(t)]^T$$

$$\underline{s}(t)=[s_1(t)s_2(t)\cdots s_m(t)]^T$$

where it is assumed to be n≧m. Furthermore, assuming that n×m mixing matrix is $\underline{A}$, which is to be a full rank matrix, i.e., a matrix where an inverse matrix of m×m matrix $\underline{A}^H\underline{A}$ exists. Hereinafter, a lowercase letter with an underline represents a vector, an uppercase letter with an underline represents a matrix, a ~~subscript~~superscript T represents transposition, and a ~~subscript~~superscript H represents Hermitian conjugate (i.e., conjugate transposition).

Page 4, line 19 through page 5, line 23.

However, as the probability distribution of original signals is practically unknown, the mutual information can not be made directly to be an object of minimization operation. Therefore, the signal separation is often performed by optimizing a valuation amount that is equal or approximately equal to the mutual information. For example, literature 1 "International Journal of Neural Systems", vol. 8, Nos. 5 & 6, pp. 661-678, October/December 1997, describes that a mutual information is able to be minimized if finding a transformation matrix $\underline{W}$ that optimizes the sum of the fourth-order cumulants with a zero time delay for each

original signal (i.e., maximizing if the kurtosis is positive or minimizing if the kurtosis is negative), on the condition that the observed signals have a kurtosis with the same sign, a covariance matrix is bounded, whitening has been performed, and a separation matrix $\underline{W}$ is a unitary matrix (i.e., $\underline{W}^H \underline{W} = \underline{I}$ (unit matrix)). Note that the kurtosis refers to a numeric obtained by the following calculation for an observed signal u_i.

[Equation 5]

$$E\{u_i^4\} - 3[E\{u_i^2\}]^2$$

where $E[\cdot]$ represents an expectation operation. The whitening means making signal vectors uncorrelated each other to make the variance 1, the fourth-order cumulant is a statistic represented by the following equation.

[Equation 6]

$$\begin{aligned} c_4(k_1, k_2, k_3) = E\{&u_i(t)u_i(t+k_1)u_i(t+k_2)u_i(t+k_3)\} \\ &- E\{u_i(t)u_i(t+k_1)\}E\{u_i(t+k_2)u_i(t+k_3)\} \\ &- E\{u_i(t)u_i(t+k_2)\}E\{u_i(t+k_1)u_i(t+k_3)\} \\ &- E\{u_i(t)u_i(t+k_3)\}E\{u_i(t+k_1)u_i(t+k_2)\} \end{aligned}$$

The zero time delay means that k_1, k_2 and k_3 are zero in the above equation.

Page Page 15, line 5 through line 13.

A signal separation method according to the invention is applied to the field of extracting an accurate change of brain activity when restoring a medical image to extract necessary information from medical images such as fMRI (functional magnetic resonance imaging). It is also applied to extraction of an original image prior to blurring by enhancing and restoring a blurred image, or noise reduction by means of image reconstruction using feature extracting components of an observed image that

~~interfered~~is contaminated by noise. Furthermore, it is conceivable that the present invention will be applied to classification and recognition of face data or multidimensional data by means of feature extracting components of observed multidimensional signals of images or the like, including face recognition in biometrics or geographic analysis from satellites. That is, a signal separation method according to the present invention is widely applicable to a problem that needs to separate original signals only from signals where a general multidimensional signal train is observed in mixed state, irrespective of the state of the digital observed signals or analog observed signals, complex signals or real signals, etc., wherein the application of its derivative forms may be widely derived, so being not limited to the above examples. Note that a signal separation technique according to the present invention can be useful with a dedicated apparatus or a terminal, as well as a computer system having a variety of memories, controllers, and a display, etc.

Page 17, line 14 through line 24.

In addition, though various proposals have been provided as to what kind of nonlinear function should be used, it is common to use threshold processing for changing a function to be used depending on whether the kurtosis of the observed signals is positive or negative, thereby selecting a function that enables an appropriate approximation of high order cumulants. Other various types of forms are also conceivable. Functions to be used include $\tanh(u)$, u^3, or $u-\tanh(u)$, etc. For example, $u-\tanh(u)$ is used when the kurtosis is positive, while_tanh(u) is used when the kurtosis is negative.

Page 19, line 17 through page 20, line 5.

In the calculation of $\underline{h}(t)$ 25, $\underline{h}(t)$ is calculated from $\underline{P}(t-1)$ at the previous time and $\underline{y}(t)$. In the calculation of $\underline{g}(t)$ and ξ 26, each value is calculated using a forgetting factor β. This forgetting factor β is a constant of $0<\beta\leqq 1$, which may be usually 1, however, when a matrix $\underline{W}$ to be estimated varies with time, this forgetting factor β is set to smaller than 1 such as 0.99 or 0.98 to enable tracking for this varying. In the calculation of $\underline{P}(t)$ 27, $\underline{P}(t)$ is calculated, which is an inverse matrix of a covariance matrix of $\underline{y}(t)$, from $\underline{h}(t)$ calculated in the calculation of $\underline{h}(t)$ 25, input α, the forgetting factor β, and $\underline{g}(t)$ and ξ calculated in the calculation of $\underline{g}(t)$ and ξ 26. Note that initial values $\underline{P}(0)$ and $\underline{W}(0)$ are arbitrarily selected for these algorithms.

Page 21, line 12 through line 23.

The algorithm shown in Fig. 4 is represented as follows.
[Equation 13]

$$y_i(t)=f(\underline{w_i}^H(t-1)\underline{x_i}(t))$$

$$\alpha=1-\gamma^{-2}$$

$$\underline{e_i}(t)=\underline{x_i}(t)-\underline{w_i}(t-1)y_i(t)$$

$$\xi=\frac{\beta d_i(t-1)+y_i(t)^* y_i(t)}{\beta d_i(t-1)+\alpha y_i(t)^* y_i(t)}$$

$$\frac{1}{d_i(t)}=\frac{1}{\beta}\left\{\frac{1}{d_i(t-1)}-\alpha\xi\frac{y_i(t)^* y_i(t)}{d_i(t-1)\{\beta d_i(t-1)+y_i(t)^* y_i(t)\}}\right\}$$

$$\underline{w_i}(t)=\underline{w_i}(t-1)+\underline{e_i}(t)[y_i(t)^*/\{\beta d_i(t-1)+y_i(t)y_i(t)^*\}]$$

$$\underline{x_{i+1}}(t)=\underline{x_i}(t)-\underline{w_i}(t)\underline{y_i}(t)$$

where $d_i(0)$ is any initial value, a ~~subscript~~superscriptrepresents conjugate. $f(\cdot)$ represents a nonlinear function such as—tanh(·).

Page 21, line 24 through page 22, line 9.

In Fig. 4, a flow of main algorithm is represented by a nonlinear function 41, calculation of an error signal $\underline{e_i}(t)$ 42, update of $\underline{w_i}(t)$ 43, and update of $\underline{x_{i+1}}(t)$ 45, wherein various amounts necessary for this main algorithm are calculated by each unit including calculation of ξ 46 and calculation of $\underline{d_i}(t)$ 47. z^{-1} is a delay for timing adjustment. The accuracy is enhanced by performing a unitarization operation when each $\underline{w_i}(t)$ is found or when all $\underline{w_i}(t)$ are found. For example, in the case of a real vector, Gram-Schmidt orthogonalization process may be applied, however, there is no need to restrict a method.

Page 32, line 13 through line 24.

(3) Noise reduction by the image reconstruction using feature extracting components of the observed images ~~interfered~~contaminated by noise

After classifying the observed images ~~interfered~~contaminated by noise into some independent components by the independent components~~-~~ analysis, noise reduction is performed by removing the components that

are regarded as noise and synthesizing using an inverse matrix of the separation matrix. As the method of the present invention has tolerance to noise, more accurate independent components than the prior art can be extracted, thereby allowing more efficient noise reduction.

Page 35, line 5 through line 22.

[Description of the Symbols]

21: Nonlinear function

22: Calculation of error signal $\underline{e}(t)$

23: Update of $\underline{W}(t)$

24: Unitarization operation

25: Calculation of $\underline{h}(t)$

26: Calculation of $\underline{g}(t)$ and ξ

27: Calculation of $\underline{P}(t)$

31: Estimation filtering of $\underline{w_1}(t)$

32: Estimation filtering of $\underline{w_2}(t)$

33: Estimation filtering of $\underline{w_m}(t)$

41: Nonlinear function

42: Calculation of error signal $\underline{e_i}(t)$

43: Update of $\underline{w_i}(t)$

45: Update of $\underline{x_{i+1}}(t)$

46: Calculation of ξ

47: Calculation of $\underline{d_i}(t)$